Modelling the closest double degenerate system RX J0806.3+1527 and its decreasing period

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ABSTRACT

In the hypothesis that the 5.4m binary RX J0806+15 consists of a low mass helium white dwarf (donor) transferring mass towards its more massive white dwarf companion (primary), we consider as possible donors white dwarfs which are the result of common envelope evolution occurring when the helium core mass of the progenitor giant was still very small ($\lesssim 0.2\mathrm{M}_\odot$), so that they are surrounded by a quite massive hydrogen envelope ($\simeq$1/100$\mathrm{M}_\odot$or larger), and live for a very long time supported by proton–proton burning. Mass transfer from such low mass white dwarfs very probably starts during the hydrogen burning stage, and the donor structure will remain dominated by the burning shell until it loses all the hydrogen envelope and begins transferring helium.

We model mass transfer from these low mass white dwarfs, and show that the radius of the donor decreases while they shed the hydrogen envelope. This radius behavior, which is due to the fact that the white dwarf is not fully degenerate, has two important consequences on the evolution of the binary: 1) the orbital period decreases, with a timescale consistent with the period decrease of the binary RX J0806+15; 2) the mass transfer rate is a factor of about 10 smaller than from a fully degenerate white dwarf, easing the problem connected with the small X–ray luminosity of this object. The possibility that such evolution describes the system RX J0806+15 is also consistent with the possible presence of hydrogen in the optical spectrum of the star, whose confirmation would become a test of the model.

Subject headings: stars:individual: RX J0806+15, RX J1914+24— stars:white dwarfs –binaries: interacting — gravitational waves

1. Introduction

The X ray source RX J0806.3+1527, discovered by ROSAT in 1990 (Beuermann et al. 1999), is variable with a period of 321.5s (Israel et al. 1999), which resulted to be also the only variability period in the optical and infrared light curves (Ramsay et al. 2002; Israel et al. 2002). This promoted the interpretation of the 321.5s as an orbital period (Burwitz & Reinsch 2001), in a system similar to V407 Vul (RX J1914.4+2456, P=570s), for which Cropper et al. (1998) had proposed a "double degenerate polar" model. In this interpretation, the two systems RXJ0806.3+1527 and V407 Vul would be the shortest period double degenerate white dwarf (DDWD) systems, progenitors of the class dubbed AM CVn, having helium dominated spectra and $P_{\rm orb}$ from 10 to 65m. The DDWD systems (both interacting and detached) might be a dominant source of low frequency gravitational waves in the Galaxy (Hils et al. 1990; Nelemans et al. 2001) and a fraction of them could even be progenitors of Type I supernovae.

The nature of the soft X-ray emission detected from RX J0806.3+1527 and RX J1914.4+2456 is still debated. Several models have been proposed (see Cropper et al. 2003 and reference therein). In addition to the polar–like model, in which the accreting WD is magnetic, a "direct–impact" accretion model on a non magnetic WD has been proposed (Marsh & Steeghs 2002).

One problem with the mass transfer interpretation of both RXJ0806.3+1527 and RX J1914.4+2456 is their period derivative, which is negative in both cases, while it is to be expected that stable mass transfer between WDs will produce increasing orbital periods. Han & Webbink (1999) notice that indeed finite- temperature white dwarfs depart significantly from zero temperature white dwarfs only in their partially or non degenerate outer envelopes: as soon as these layers are stripped away by mass loss, the interiors behave practically indistinguishably from fully degenerate white dwarfs, and their adiabatic mass radius exponent is then negative. If the radius increases when the mass decreases due to mass loss, the orbital period must indeed increase, unless the mass transfer is unstable. The problem of the decreasing period of this system has been a motivation to fully develop alternative models, such as the unipolar inductor model (Wu et al. 2002; Dall'Osso et al. 2006) or the intermediate polar model (e.g. Norton et al. 2004), in which the 5.4m period is suggested to be the WD spin period. Notice that direct accretion –no disk– models (which probably apply to this case) worsen the problem of the period derivative, and indeed act to destabilize the mass transfer. The unipolar inductor model has also been criticized by Marsh & Nelemans (2005), who also propose that the negative period derivative can be explained if the mass transfer rate can be pushed away from its equilibrium value.

There are two other problems for the interpretation of RXJ0806.3+1527 as a DDWD:

i) the X-ray luminosity of the source is quite low: in the range 0.5–2.5keV it is only $\simeq 2 \times 10^{33}(\mathrm{d/1kpc})^2$ erg s^{-1}, that is $\sim 5 \times 10^{32}$erg s^{-1} for a distance of 500pc (Israel et al. 2003), while the value predicted in the case of mass transfer driven by gravitational radiation (GR) is $\sim 10^{35}$erg s^{-1} (Israel et al. 2002). This value can be reduced to $\sim 2 \times 10^{33}$erg s^{-1} in the case of highly non conservative mass transfer and very low mass ($\lesssim 0.35\mathrm{M}_\odot$) accreting WD primary (Willems & Kalogera 2005). Another possible caveat to this problem is that the primary WD may be affected by compressional heating, which could bring it at an absolute $\mathrm{M}_v \sim 4.7$ and $T_{\rm eff} \sim 140000$K according to Bildsten et al. (2006). In this case the distance would be much larger, ∼20kps, 8kpc above the galactic plane, and the X-ray luminosity would be consistent with that predicted by a GR driven mass transfer rate.

ii) There is some evidence that the optical spectrum of RX J0806+15 shows the presence of hydrogen (Norton et al. 2004), with a non negligible abundance (Steiper et al. 2005): also this feature, if confirmed, *apparently* argues against the DDWD scenario.

In this paper we study the evolution of DDWDs by following the mass transfer phases with a complete stellar evolution code, and assuming a quasi–evolutionary structure for the donor WD. One or two common envelope phases must have occurred in the binary story before the present phase of mass transfer, so it is not possible to model consistently the whole evolution of the binary with hydrostatic codes. Nevertheless, we provide insight about which are possible starting conditions for the mass loss from a degenerate dwarf. We propose that RXJ0806.3+1527, and possibly also V407 Vul, are indeed DDWDs, but that we see them during those phases of mass transfer, during which the structure of the external layers of the donor WD is dominated by the p-p hydrogen shell burning, so that the stellar radius contracts in response to mass loss. Thus we obtain both a period derivative correct in sign and order of magnitude, and the solution of the conundrum of the optical spectrum and of the low X–ray emission.

2. Choice of the starting models

In order to obtain a binary formed by two WDs, the lighter of which fills its Roche lobe and transfers mass to the other, we need that the orbital period at the end of the mass transfer phase which forms the second (lighter) WD is quite short (at most $\sim$ 5hr for the cases of interest here), so that gravitational radiation can bring into contact the two WDs within the Hubble time. This consideration favors evolutionary channels in which the primary is a small mass WD, so that the mass transfer from the secondary component of the system is highly unstable, and a common envelope is formed. Mass transfer from WDs is in many cases dynamically unstable (Han & Webbink 1999) or occurs at very high super-Eddington rates, so we further suggest that the secondary WD in the progenitor of RX J0806+150806 is a very low mass WD, remnant of evolution starting when the star is still at the bottom of the red giant branch. Also this choice favors the formation of very close double degenerate systems, whose orbit can decay significantly due to emission of GR.

Therefore, we assume that our system traverses three stages of mass transfer:

1) a common envelope which has left the primary white dwarf (we will consider masses as low as $0.35M_\odot$for helium primaries) in orbit with the companion, still in main sequence; the separation is such that the secondary begins mass transfer as soon as it has reached the red giant branch, and its helium core mass is still below $\sim 0.2M_\odot$. Final orbital periods must be $\lesssim 2$ days to allow this situation.

2) A second common envelope phase, due to the mass transfer from the evolving subgiant to the primary WD; the starting mass must be larger than $\sim 1M_\odot$, so that the star can evolve off the main sequence within a reasonable lifetime. A second white dwarf of $0.18 - 0.22M_\odot$is formed, and the orbital period is of a few hours.

3) Gravitational radiation brings the second WD into contact and a third phase of mass transfer begins.

We can not model the common envelope phases with a hydrostatic code. Nevertheless, we can infer the structural properties of the low mass white dwarf. Previous computations simulating mass transfer which leads to the formation of a helium WD (e.g Driebe et al. 1999; Althaus et al. 2001) have been done assuming that the evolving giant of $1M_\odot$ is subject to constant mass loss rates which leaves it in thermal equilibrium. Other works compute consistently the binary evolution, but have been performed for systems having companion of typical neutron star mass $\sim 1.35M_\odot$(Sarna et al. 1999; D'Antona et al. 2006), so that the mass transfer is stable (no common envelope). The remnant of these evolutions are WDs with thick hydrogen envelopes, which either undergo stable p-p burning (for masses $M \lesssim 0.2M_\odot$) or suffer a series of hydrogen shell flashes. The occurrence of thermal instabilities is also linked to the detailed computation of helium diffusion in the envelopes of the WD (Althaus et al. 2001), and is important in the context of dating the binary millisecond pulsars through the age of their companion WD. In particular, the consistency which must be found between the WD companion cooling age and the spin–down age in these systems implies that only the lowest mass WD companions may preserve thick hydrogen envelopes, which live for several billion years in the p-p burning phase. The system PSR J1012+5307 has a spin–down age of ~ 7Gyr (Lorimer et al. 1995). This is consistent with the age of the companion WD, if this latter is stably burning hydrogen. This case confirms that indeed hydrogen burning occur in very low mass WDs. Other observational evidence for the existence of very low mass, long-lived, WDs comes from the optical companions of a few millisecond pulsars in Globular Clusters (Ferraro 2006). On the contrary, there is no clear evidence for a population of non interacting short period binaries hosting a luminous low mass WD. This may be telling us *1)* either that the duration of the non interacting phase, which depends on the distribution of orbital periods following the common envelope, is short; *2)* or that this evolution is not common: in fact it concerns only the WDs remnants of binary evolution and having mass $0.17 \lesssim \mathrm{M/M_\odot} \lesssim 0.21$. Smaller mass WDs can not be formed, and higher mass WDs will suffer thermal instabilities which consume the thick hydrogen envelope and shorten the p-p burning evolutionary phase.

If the binary suffers a common envelope, the mass losing giant does not preserve thermal equilibrium. We have done numerical experiments (which will be fully presented elsewhere) by imposing huge rates of mass loss ($10^{-5} - 10^{-4}\mathrm{M_\odot/yr}$) to a giant of $1.1\mathrm{M_\odot}$ having a core mass of $0.188\mathrm{M_\odot}$. We found out that, if the binary detaches at an orbital period of a few hours, the hydrogen mass remnant on the helium core is much larger than the maximum mass remnant at the WD stage. Therefore, the star will regain thermal equilibrium and burn all the extra-hydrogen before ending as a white dwarf with a thick hydrogen envelope. Should the recovery of thermal equilibrium bring again the star into contact with its Roche lobe, mass transfer now will be stable, as the mass ratio is reversed. Thus we conclude that there are no reasons to expect that the common envelope phase will not maintain a thick hydrogen envelope on the remnant WD.

We should also worry about the possible merging of the two stars, if the energy extracted from the orbital motion during the spiral in is not efficiently deposited into the envelope which has to be lost. In the simplest approximation (see, for a discussion Iben & Livio 1993) we can write:

$$\frac{M_1^2}{A_0} = \alpha \frac{M_{1R} M_2}{A_f} \tag{1}$$

being A_0 and A_f the initial and final separation, M_1 and M_2 the initial masses, and M_{1R} the final mass of the donor after the common envelope phase. A value of α in the range 0.8-1.6 is necessary for the typical values $M_1 = 1.1\mathrm{M_\odot}$ for the initial mass of the giant, $M_{1R} = 0.2\mathrm{M_\odot}$ for the remnant WD, M_2=$0.5\mathrm{M_\odot}$ for the primary WD, an initial period of 40hr and final period of 1-2hr. A deeper discussion is out of the purpose of this work. An interesting discussion on the common envelope evolution of observed DDWD systems is provided by Nelemans et al. (2000).

With the assumption that the hydrogen remnant envelope of a low mass WD emerging from common envelope can not be substantially different from that of a WD having the same mass, but that is a remnant of conservative or quasi-conservative evolution, we adopt as starting models some structures of WDs emerging from binary evolution without common envelope, published in D'Antona et al. (2006) in the context of the evolution of the progenitors of millisecond pulsars. Modelling of binary evolution with mass transfer from these WDs will pass through the $P_{\rm orb}$ of RX J0806+15, and these evolutions constitute the main results of this study.

We build up our stellar models by the ATON2.1 code, whose input physics is described in Ventura et al. (1998), while the binary evolution routines follow the description in D'Antona et al. (1989). The mass transfer rate is computed explicitly following Ritter (1988), for the optically thin case, and Savonije (1978) for the optically thick case. Mass transfer is considered conservative below the Eddington limit for the primary WD, and the exceeding mass is considered to be lost from the system with the orbital angular momentum of the primary. Eddington' rate however is never reached. We do not model accretion on the primary WD, but we should worry that, during the phase of transfer of hydrogen, it is likely to suffer recurrent shell flashes, which will bring the system again into contact. If accretion were in spherical symmetry, we could infer the mass which has to be accreted before ignition, as function of the stellar mass and of the mass transfer rate, e.g. from Fujimoto (1982). The type of system we deal with, with low WD primary mass and accretion rates in the range $10^{-9} - 10^{-7}{\rm M}_\odot$/yr would be a recurrent contact systems or a steady UV source. For a WD primary mass of $0.4{\rm M}_\odot$we expect an ignition mass of $\sim 3 \times 10^{-4}{\rm M}_\odot$, so that the most massive hydrogen envelope we have ($\sim$0.03$\rm M_\odot$) may induce $\sim$ 100 runaways. Actually in our case probably the envelope is not uniformly heated by accretion, as the X–ray modulation is probably a signature of the direct impact of accretion (Marsh & Steeghs 2002), and this number could be drastically reduced. Nevertheless, the effect of possible thermonuclear runaways on the binary evolution at orbital periods of a few minutes is certainly not negligible and may have dramatic consequences which are neglected in this work, but must be taken into account when attempting to compute the space density of such systems: we have to keep in mind that the evolution of the system when the hydrogen envelope has been completely lost might be purely hypothetical, especially for the system with a more massive primary WD, for which repeated hydrogen ignition can not be avoided. Depending on the specific angular momentum lost with the sudden mass loss associated with the thermal runaway, it is possible that the system detaches, or decreases temporarily the mass transfer rate. In this case, the gravitational radiation will soon lead the donor again to stationary mass transfer.

Table 1 lists the starting models and the binary parameters chosen for phase 3. We choose a population I WD of $0.194{\rm M}_\odot$, with different assumptions on the mass of the primary, helium diffusion, and starting radius[1] and a population II WD of $0.22{\rm M}_\odot$. The helium

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[1]For Sequence 3 the evolution begins when the WD is considerably cooler than for the other sequences, and its radius is reduced to $0.0285{\rm R}_\odot$, to be compared with a radius of $0.0445{\rm R}_\odot$ for Seq. 1 and even

gravitational and thermal diffusion is included according to the formulation by Iben & McDonald (1985).

3. The structure of the low mass helium white dwarfs and evolutionary models for RX J0806+15

All the starting WD models have a very thick hydrogen envelope remnant of the phase 2 evolution. Proton proton burning is present at the basis of the hydrogen envelope, supporting the whole stellar luminosity. In the models with helium diffusion, the star lives indefinitely (much longer than 15Gyr) in this burning phase. Althaus et al. (2001) find "diffusion induced" thermonuclear hydrogen flashes in similar WDs, for masses larger than $0.18M_{\odot}$. We do not find such flashes in our models of $0.194M_{\odot}$. Sequence 4, in which the WD has $0.22M_{\odot}$, should indeed show hydrogen flashes, but we do not find them as we did not include diffusion in this latter sequence, in this exploratory study. This is a crucial point, which deserves further exploration, as, when flashes occur, the hydrogen envelope is consumed, with consequences for our third mass transfer epoch.

We start mass transfer from our WDs while they are in the hydrogen burning stage. The initial orbital periods range from 7.6m to 15m. The shorter period refers to the higher mass WD ($0.22M_{\odot}$, sequence 4) and the longer one to the smaller mass including helium diffusion (sequence 2). This difference is simply due to the different radii of the donor at the beginning of the mass transfer phase. For a smaller initial mass (down to a minimum mass of $\sim 0.18M_{\odot}$) we may have longer initial periods. Radius, mass and mass transfer rate versus orbital period are shown in Fig. 1 for the sequences 1, 2 and 3. We see that the radius decreases (and the period obviously decreases too) while the mass changes only by a few percent of $M_{\odot}$. Only when the hydrogen envelope if fully consumed, the radius begins increasing again, as its behavior is now dominated by the WD degeneracy. The differences among the models plotted in Fig.1 are subtly induced by the details of the envelope structure, which is well out of thermal equilibrium during this whole phase. When the hydrogen envelope is fully lost the sequences converge to a unique mass transfer rate versus period relation. We see that the orbital period decreases during the first phase, in which only the hydrogen envelope is lost, it reaches a minimum of $\sim$4.6min, then it increases during the most important phase of mass transfer. So the periods of RX J0806+15 and RX J1914+24 are touched twice: first during the shrinking of the radius, and then during the "normal" phase of mass transfer

$0.0541R_{\odot}$ for Seq. 2, including diffusion.

from the now pure helium WD[2]. The mass transfer rate $\dot{M}$ is much smaller, up to a factor 10, when the period is decreasing. The period derivative is shown in Fig. 2, in which we see that the value of $\dot{P}_{\rm orb}$ for RX J0806+15 is in the range provided by our models. The $\dot{P}_{\rm orb}$ of RX J1914+24 (V407 Vul) is much smaller (in spite of the larger X–ray luminosity): it would be better explained with a positive $\dot{P}_{\rm orb}$ and stronger mass transfer rate, but the exploratory aim of these computations does not pretend to look for a precise fit of the $\dot{P}_{\rm orb}$ and we do not fully explore the whole range of space parameters for this kind of evolution. Taken at face value, the results might indicate that RX J1914+24 is still *beginning* the mass transfer phase. The onset of mass transfer is shown in Fig. 2 for sequence 4, and it occurs at an orbital period slightly shorter than the period of V407 Vul.

From the bottom panel of Fig. 1, we see that the mass loss rate at 5.4m for the lower branch (decreasing orbital periods) is in the range $2 - 5 \times 10^{-8}$M$_\odot$/yr, while it is $\sim 2.5 \times 10^{-7}$M$_\odot$/yr for the upper branch (increasing period). Consequently the standard expected X–ray luminosity would be reduced from $2{\times}10^{35}$erg s^{-1} to $\sim 2-4\times 10^{34}$erg s^{-1}. Notice that two points must be investigated in more detail before we push further the interpretation of X–ray luminosity:

i) the role of compressional heating (Bildsten et al. 2006). Although the mass transfer rates we find are quite smaller than those predicted by GR for a fully degenerate helium donor, still a rate of $\sim 2 \times 10^{-8}$ M$_\odot$/yr would raise the primary WD luminosity to M$_v$ $\sim$ 8, pushing the distance to $\sim$ 4kpc and raising the observed X–ray luminosity to $\sim 3 \times 10^{34}$erg s^{-1}, perfectly consistent with our new mass transfer rates. However, the modelling of compressional heating should be extended to smaller primary WD masses (alike the 0.35M$_\odot$ cases studied here), to assess the effect of the peculiar geometry of non sperically symmetric accretion on WDs having very extended non degenerate envelopes (only the 0.65 and 1.05M$_\odot$cases are reported in Bildsten et al. (2006)). Further studies of the system may constrain better the primary $T_{\rm eff}$ and luminosity, and then the system distance.

ii) the X–ray luminosity is a fraction of the accretion luminosity, and this latter depends on which fraction of the mass lost is actually accreted on the primary WD. There is a small range of the parameters space for which the X-ray luminosity of RX J0806+15 is compatible also with the large mass loss rate of the upper branch (Willems and Kalogera, 2005), but its reduction by a whole factor 10 makes the problem less cogent, and is a further bonus of our modelling.

The timescale of evolution for Seq. 2 is shown in Fig. 3, in which the lower branch

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[2]Similar computations were first done by Fedorova & Ergma (1989) in the context of the decreasing orbital period of the ultrashort X-ray binary MXB 1820-30 having P$_{orb}$=11.4m

corresponds to decreasing periods. We see that the ratio of lifetime for positive $\dot{P}_{\rm orb}$ to the lifetime for negative $\dot{P}_{\rm orb}$ is about a factor two at the period of RX J0806+15: thus the probability of finding the system with decreasing period is only a factor two smaller than that of finding it in the increasing period stage. This contradicts, for this system, the common sense hypothesis that it should be much more probable to see the DDWDs when the small hydrogen envelope has been lost. However the same figure shows that, at the period of RX J1914+24 , it is ~ 5 times more probable to find an increasing, rather than decreasing orbital period. This is a further problem which renders the case of RX J1914+24 not straightforward to be explained. At even longer periods, the timescale of evolution becomes longer and longer for the increasing period stage. We also remarked that only initial masses smaller than those considered could begin the mass loss phase at periods longer than $\sim$ 15m, but common envelope evolution can not end with much smaller masses. Consequently the "normal" AM CVn systems, at $P_{\rm orb} \gtrsim 15$m, should mostly be deprived of hydrogen and show increasing period.

4. Discussion and conclusions

The optical spectrum of of the V $\simeq$ 21 mag counterpart of RX J0806+15, obtained with FORS1 at the ESO VLT, shows a blue continuum with faint emission lines of HeI and HeII which are taken as strong evidence for a hydrogen depleted binary (Israel et al. 2002). Norton et al. (2004), examining this spectrum, notice that the fluxes of the emission lines corresponding to the odd terms of the He II Pickering series are at least a factor of 1.5-3 less than the fluxes of the neighboring even term transitions, indicating that the even terms may be blended by emission lines from the H Balmer series. First results of a detailed modeling of the spectrum (Steiper et al. 2005) yield a He/H abundance number ratio 0.1 <(He/H) < 0.3. Reinsch et al. (2004) suggest that such a ratio is not consistent with a helium WD donor but rather that we see emission from a hot hydrogen-rich plasma and that the dominance of He II emission is just a consequence of the high plasma temperature.

Figure 4 shows the variation of helium abundance Y (mass fraction) at the surface of Seq. 2 as a function of the stellar mass. As in this run we include helium diffusion, the helium abundance is initially zero, but it increases as soon as the layers in which helium depletion is not complete are exposed. We see that Y$\sim$0.35 when P=5.4m, corresponding to a number ratio He/H$\sim$0.12, consistent with Steiper et al. (2005) analysis. Of course, the spectral evidence is not so pregnant, and modeling of the physical conditions of this system is difficult. Nevertheless, we urge new observations, as our new models *require* the presence of hydrogen in the spectrum! The CNO abundances in the spectrum might also become a constraint of the evolutionary status of this intriguing binary (D'Antona et al., in preparation).

The novelty of the present models for the shortest periods DDWDs is that we have assumed that the donor white dwarf has a very small initial mass, so that it is a helium white dwarf with a massive hydrogen envelope which is not subject to diffusion induced hydrogen shell flashes. Due to the long phase of p-p burning, prolonged by helium diffusion, the donor may be still in this burning phase when it begins mass transfer to the primary WD. Until the whole hydrogen envelope is lost, the donor WD *contracts* in response to mass loss, the orbital period decreases, and the mass transfer rate is smaller by a factor up to ~ 10 than in the case of mass transfer from a fully degenerate helium white dwarf. This model is able to explain the decreasing orbital period of RX J0806+15, its low X ray luminosity, and the possible presence of hydrogen in the spectrum. This latter feature becomes a requirement of the model, so that it is necessary to confirm it by new spectroscopic observations and its careful model analysis. The lifetime of a system like RXJ0806.3+1527 in this phase is not more than a factor two shorter than the lifetime at the same orbital period, but when the period is increasing. This model suggests that a fraction of the double degenerate systems could be formed from common envelope evolution, ending up in the formation of a quite low mass WD with a massive hydrogen envelope. There is an important observational evidence for the existence of very low mass and long-lived hydrogen burning WDs, namely the optical companions of a few millisecond pulsars in Globular Clusters (e.g. Ferraro 2006) and the system PSR J1012+5307, in which the spin down age of the MSP is compatible with the companion WD cooling age only if this is stably burning hydrogen. Lack of a population of luminous low mass WD remnants of common envelope evolution does not necessary mean that this evolution is rare, but it may be telling us that the duration of the non interacting phase, which depends on the distribution of orbital periods following the common envelope, is short. Further exploration of the modalities of formation of these systems is necessary, if we wish to understand the consequences of this model for the background of gravitational waves emission by compact objects in the Galaxy.

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Table 1. Models

N	$M_{2,in}$	$M_{1,in}$	He-diff	P_{in}	R_{in}	Pmin(m)	$\dot{P}(5.4m)^a$	$\log(\dot{M}/M_\odot)^a$	$\log(\dot{M}/M_\odot)^b$
1	0.194	0.35	no	11.29	0.0445	4.57	-4.87×10^{-11}	-7.59	-6.59
2	0.194	0.6	yes	15.39	0.0541	4.57	-2.80×10^{-11}	-7.69	-6.68
3	0.194	0.35	no	5.874	0.0285	4.52	-1.79×10^{-11}	-7.54	-6.53
4	0.223	0.35	no	7.51	0.0355	4.01	-4.00×10^{-11}	-7.35	-6.68

[a] $\dot{P}$ and $\dot{M}$ are given at the period of RX J0806+15, for the phase in which the period is decreasing.

[b] $\dot{M}$ is given at the period of RX J0806+15, for the phase in which the period is increasing.

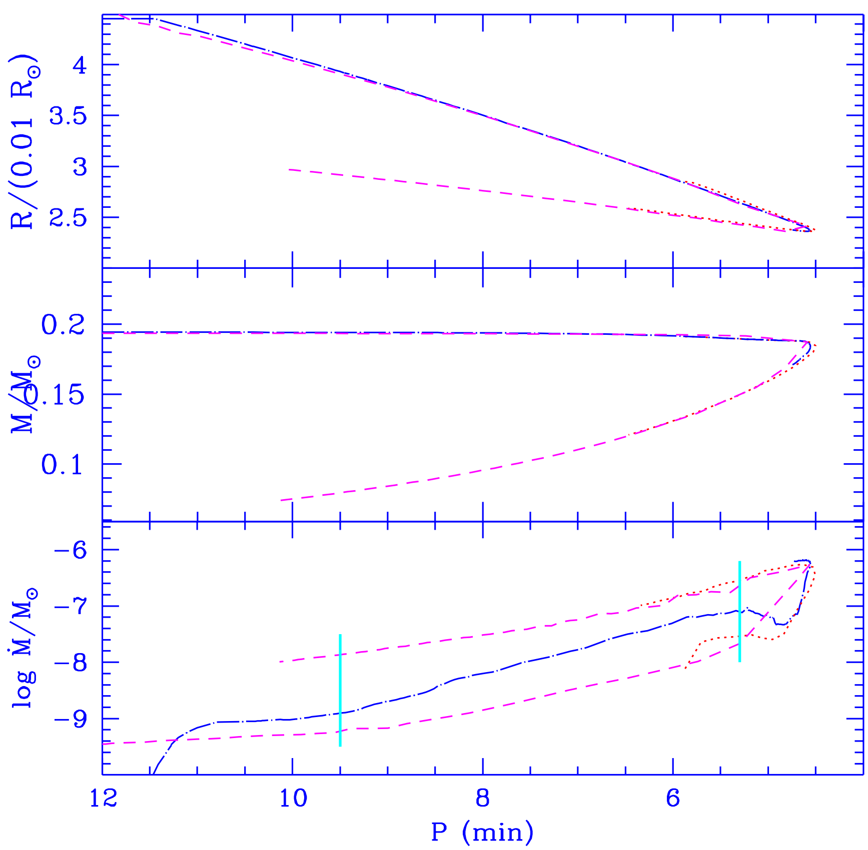

Fig. 1.— Evolution of radius, mass and mass loss rate along sequences 1 (dash-dotted), 2 (dashed) and 3 (dotted). The periods of RX J0806+15 and RX J1914+24 are indicated as vertical segments.

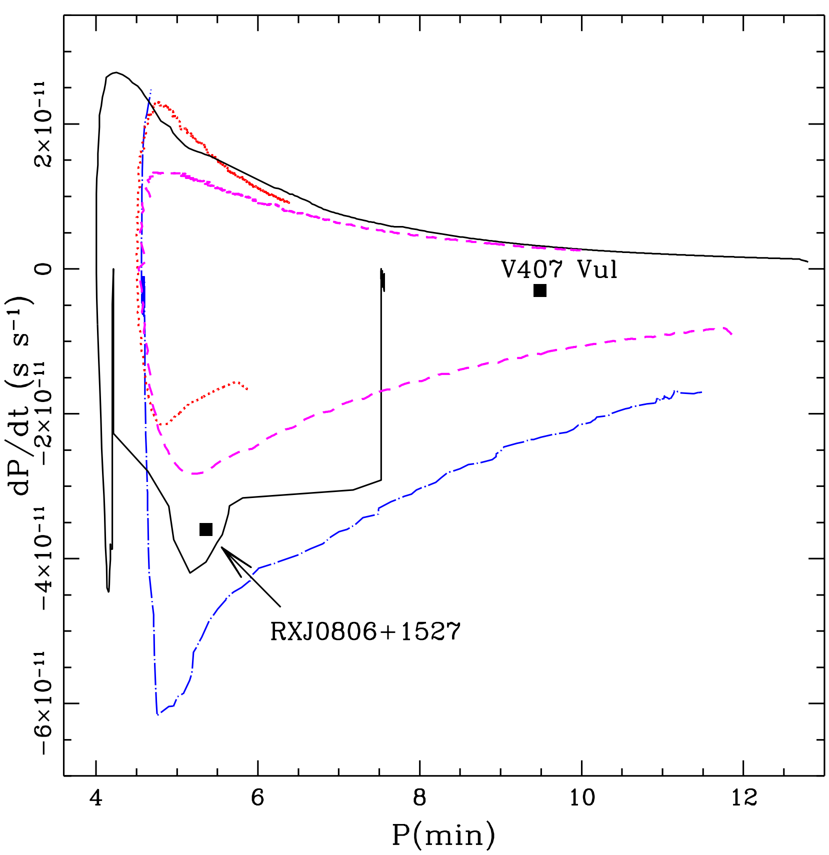

Fig. 2.— Period derivative versus orbital period for the sequences 1 (dot–dashed); 2 (dashed); 3 (dotted) and 4 (full line).

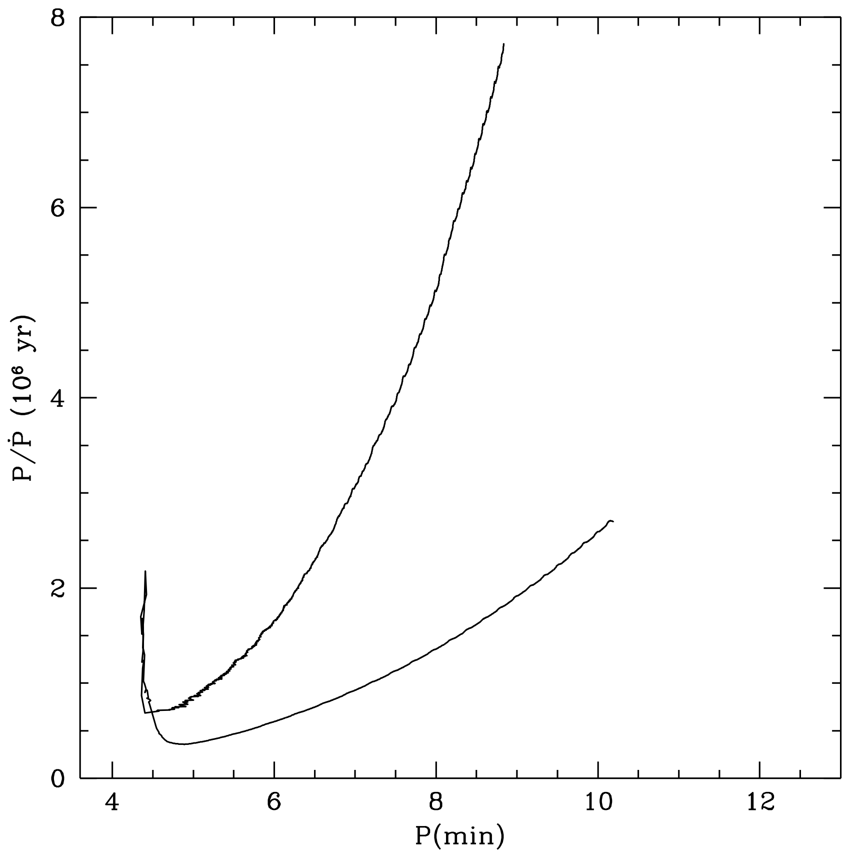

Fig. 3.— Timescale of evolution $P/\dot{P}$, versus orbital period for sequence 2. The lower portion of the curve corresponds to decreasing $P_{\rm orb}$, the upper curve to increasing $P_{\rm orb}$.

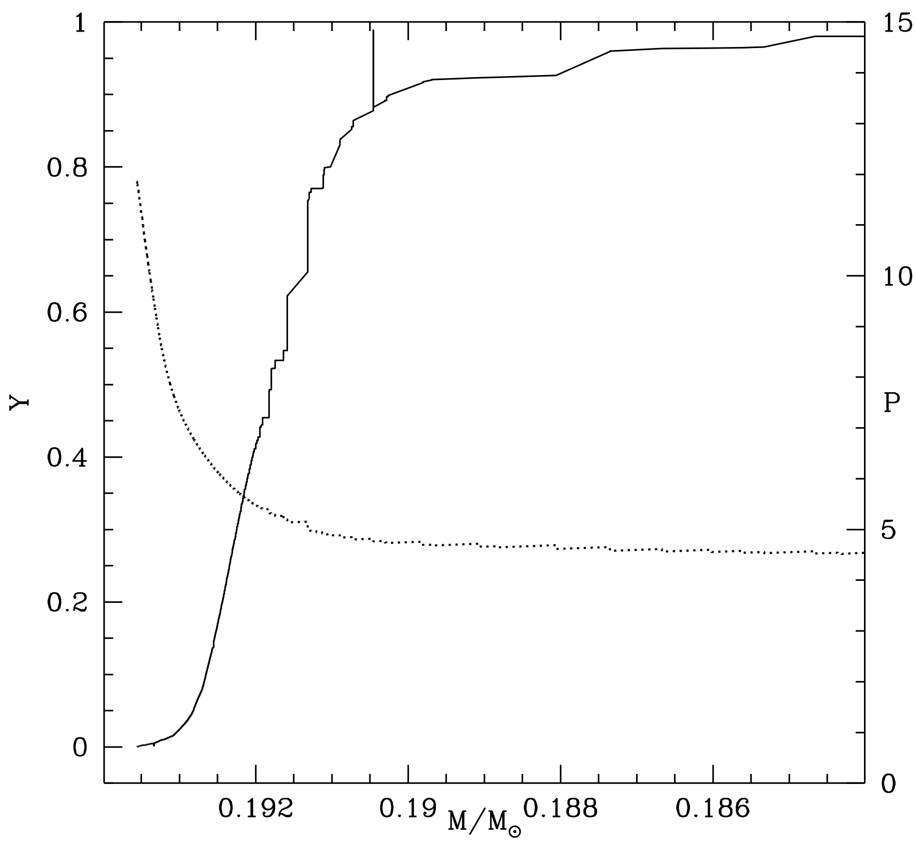

Fig. 4.— Helium abundance in the transferring matter versus mass for system 2, including helium diffusion. The orbital period versus mass is also shown (dotted). At the period of RX J0806+15 the helium abundance is $Y \sim 0.35$.